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NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407-5001

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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 06-91

# SAFE THERMAL EXPOSURE LIMITS (STEL) FOR THE EOD MK 1 MOD O DRY SUIT

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JUNE 1991

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The EOD MK 1 MOD 0 dry suit is a passive thermal system (PTS) that has been in development for over a decade. Its last evaluation was unsatisfactory and its shortcomings were identified. Improvements were made to address these shortcomings in an attempt to make this system usable by operational Navy divers. The system was sent to Navy Experimental Di ing Unit (NEDU) for evaluation. The study determined safe exposure limits at 2, 4.5, and 7°C (35, 40, 45°F). A human factors evaluation was also conducted on the EOD MK 1 MOD 0 dry suit.

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Excessive leakage of the dry suit plagued the study despite careful use under ideal laboratory conditions. Additional modifications to the weight vest, gloves, and urinary overboard dump system were presented. The suit inflation bottle was inadequate. Overall, the system performed marginally.

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Jesse Uriquidez - EOD Technology Center
Teresa Barth - NCSC
CDR Gripp* - Commanding Officer EOD Training and Evaluation Unit 2
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*Denotes those who made actual dives with the dry suit in the test pool.

Special thanks to the following individuals for their tireless support of this project:

GMGC(DV) Petersen: Diving Supervisor
Mr. Mace, Mr. Galloway, Mr. Turner: DP support
Mr. Boone, HMC(DV) Wakefield: Technical support
HM2(DV) Burford, HM3 Moore: Medical support
Mrs. Thornton: Administrative support

The respect and admiration of the entire diving community is extended to the divers of EOD's Mobile Unit 2. Your enthusiastic, professional performance throughout the entire dive despite repeated lengthy exposure in near freezing water was inspirational. These divers were:

AOCS(DV) Wolfe
ENC(DV) Ellinwood
AD1(DV) Krieg
AME2(DV) Finley
GMM2(DV) Tate
BM1 Zirizina
LT Coster (OIC)
OS1(DV) Drake

MMC(DV) Ashton from NEDU served as project officer for this evaluation. In addition, he volunteered as a test diver when an unexpected injury medically disqualified one member of the original dive team.

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# I. INTRODUCTION

Advances in underwater breathing apparatus (UBAs) have increased both depth and time limits for divers. Unfortunately, the advances in passive thermal protection have not kept pace with these developments and are now the limiting factor in dive planning. This study established safe thermal exposure limits (STEL) for an ensemble of dry suit and undergarments called the EOD MK 1 MOD 0 dry suit, a passive thermal system (PTS). A limiting factor for thermal protection when diving in near-freezing water is extremity hypothermia (e.g., fingers) which can lead to loss of hand dexterity and permanent tissue damage called nonfreezing cold injury (NCI) [1]. In a passive thermal system extremity hypothermia usually occurs before body core hypothermia . A previous study demonstrated that this PTS could not protect the diver for the required five hours in near freezing water nor did the suit inflation bottle have adequate volume for dives to 300 fsw [2].

To avoid NCI, digit temperature termination criteria of 8°C was originally proposed and used by Thalmann, Schedlich and Broome, et al.[3]. It was also used by Adkisson, Anthony and Florio [4] during laboratory dives in 2°-5°C water. No comments were made regarding NCI occurrance during these dives [2-4]. Despite transient symptoms of paresthesia, with documented hypesthesia, NCI was not observed in a subsequent study [5]. Identical termination criteria was used in this evaluation.

This study involved dives in 2°C (35°F), 4.5°C (40°F), and 7°C (45°F) fresh water with the MK 1 MOD 0 dry suit worn by U.S. Navy Explosive Ordnance Disposal (EOD) technicians. These water temperatures correspond with the range of temperatures common to EOD cold water operations. In addition, the testing was confined only to those lower temperatures that would have a physical impact on the skin temperature termination criteria of 8°C. The STEL determined for this PTS was based on the average time it took for the extremity temperatures to reach termination criteria. If the dry suit remained dry, core temperature did not reach termination criteria.

# II. METHODS

## A. DIVER SUBJECTS

Nine USN EOD divers voluntarily participated in this study. All divers were highly qualified in the use of the MK 16 closed-circuit UBA and in dry suit diving procedures.

Percent body fat was determined by four-site skin fold thickness using skin fold calipers [6]. All subjects were medically screened and found to be in good health, free of any medical problems. Diver #9 tore the lateral meniscus in his left knee. Immediate arthroscopic surgery, effective rehabilitation and the high level of motivation characteristic of this entire EOD dive team enabled him to be medically cleared for the dive series at 4.5°C. Diver #8 substituted for him at the other two temperatures. No changes were made in the divers' diet except that a breakfast was required the day of their dive as well as attention to adequate hydration. No alcohol was allowed 24 hours prior to diving and caffeine consumption before diving was discouraged. The motivation throughout the series was outstanding, despite the fact each diver was required to perform several additional cold water exposures due to the flooding of the dry suit. Table 1 lists the divers' anthropometric data.

**TABLE 1**

**THE DIVERS' ANTHROPOMETRIC MEASUREMENTS**

| Diver # | AGE (yrs) | HT (inch/cm) | WT (lbs/kg) | Body Fat (%) |
|---|---|---|---|---|
| 1 | 37 | 68/173 | 164/74 | 22.1 |
| 2 | 32 | 69/175 | 198/79 | 24.5 |
| 3 | 36 | 70/178 | 173/78 | 22.3 |
| 4 | 26 | 69/175 | 155/70 | 9.1 |
| 5 | 27 | 69/175 | 204/93 | 22.7 |
| 6 | 28 | 67/170 | 155/70 | 14.3 |
| 7 | 31 | 73/185 | 190/86 | 21 3 |
| 8 | 33 | 72/182 | 180/82 | 18.3 |
| 9 | 33 | 71/180 | 189/85 | 18.2 |
| Average | 31 | 70/177 | 178/81 | 19.2 |
| Standard Deviation | 4 | 2/5 | 18/8 | 4.9 |

## B. DIVING EQUIPMENT

### 1. Underwater Breathing Apparatus

The MK 16 UBA was used throughout the study. The MK 16 is a closed circuit constant 0.75 atmospheres absolute (ATA) oxygen UBA. The MK 16 has a limit of 300 minutes in the temperature range of this study based on its tested $CO_2$ scrubbing capability and $O_2$ supply [2]. A helium-oxygen (heliox) mixture was used since it would be the gas mixture used operationally. Heliox also results in increased respiratory heat loss as compared to nitrogen-oxygen (nitrox) mixtures.

2. Diver Dress

The divers were dressed from skin surface outward as follows: A one piece polypropylene body suit over physiological instrumentation, a two-piece M-400 thinsulate undergarment (Diving Unlimited International (DUI), San Diego, CA) followed by the MK 1 MOD 0 dry suit (DUI). A detached crushed foam wet hood over M-400 thinsulate was worn on the head. M-400 thinsulate is designated as type 2 on the garment's inside label for identification. Type 1 designates M-200 thinsulate.

Hands were protected initially with a detachable dry three-fingered glove (DUI) with the stalls configured with the thumb alone in the first stall, second and third fingers in the second stall and the remaining fingers in the last stall, designated as the T-2-2 configuration. A cotton insert was worn over the hand before inserting the hand into the glove. The wrist seal was accomplished with a detachable, double O-ring, molded plastic male and female joint assembly (DUI). This glove had a non-adjustable relief valve attached to the dorsal aspect of the glove. The valve was designed to allow dry suit gas trapped in the gloves to vent on ascent. Previous dives without this valve resulted in the gloves blowing off on ascent due to the expanding gas within the glove . This left the hands unprotected and flooded the dry suit. Unfortunately, substantial leakage through this valve and at the O-ring seal occurred during the work-up phase. A modified dry suit glove by Viking, Inc. was successfully substituted. The Viking, Inc. glove employed the same three-fingered stall arrangement, with insert, but required no relief valve and had a soft rubber apron that formed a watertight seal at the wrist.

The feet were protected with M-400 thinsulate booties worn over top heavy athletic socks before donning the dry suit. Dry suit fins were worn to induce foot compression caused by the fin straps that would be seen while diving.

A weight vest (Alpha model, Zeagle, Zephyrills, FL) was worn that centered the weight below the waistline for better weight distribution. A velcro strap was added across the chest to better secure the vest to the diver.

The AGA (Interspiro, Branford, Ct.) full face mask (FFM) with a reduced volume faceplate along with the Naval Coastal Systems Center (NCSC) switchover mechanism was used to provide full face protection. The switchover mechanism enables the diver to switch from gas supplied from the UBA to gas from a surface supplied umbilical. This is done by means of a quick disconnect fitting and a lever on the faceplate assembly enabling rapid switching between closed and open-circuit breathing at depth.

## C. EXPERIMENTAL DESIGN

### 1. Dry Suit Evaluation - Test Pool

All thermal testing was conducted in the NEDU test pool. This pool is 4.6 m (15 ft) deep. The facility includes two rewarming tubs, an installed diver monitoring system and a means to strictly control the pool temperature.

The evaluation utilized the MK 1 MOD 0 dry suit in the same configuration issued for use by USN EOD divers with the modifications detailed in section B. As mentioned, these modifications were made during the work-up phase in order to proceed with the evaluation. If the configuration changes to the gloves, the weight vest, and the urinary overboard dump system had not been made, the ensemble would have failed during the work-up phase and been given the same thermal limits as a wet suit. Careful control of any modifications made this study's findings directly applicable for fleet diving operations.

The dives were conducted at three different temperatures with a minimum of eight man-dives conducted at each temperature. The temperatures chosen for this study were from near-freezing to warmer temperatures, where other forms of PTS can be used [7]. Initially, testing was to be conducted at 2, 7 and 12°C. After it was observed that divers at 7°C were completing the full 300-minute mission scenario when no leaking occurred, it was concluded that dives conducted at warmer temperatures would also complete the required five-hour duration. The dives planned for 12°C were not needed and a series at 4.5°C was performed instead. The 6°/8°C extremity termination criteria, detailed later in this report, controlled the duration of these dives. Water temperature of 8°C would be the warmest temperature impacting duration for a watertight dry suit using M-400 thinsulate within 5 hours. Boutlier found skin temperatures actually remained 1.3°C above the ambient water temperature at equilibrium [8]. This would indicate that theoretically, the coldest water temperature that would allow the full 5-hour duration would be 6.7°C once equilibrium is reached. Two MK 16 divers were studied simultaneously with one set of dives planned each day beginning in the morning. Dives were planned in the morning to avoid any potential influence of circadian rhythm.

The actual dive scenario simulated by this study is the long decompression obligation incurred by a MK 16 diver who had made a deep dive in near-freezing water diving mixed gas (heliox). The dive profile consisted of descending into the chilled test pool to a depth of 4.6 m (15 ft) and remaining until reaching termination criteria or 300 minutes had elapsed. The divers remained at rest on the bottom to simulate a long decompression schedule. Data was collected utilizing the NEDU on-line Diver Monitoring System (DMS) measuring critical skin and body core temperatures. Electrocardiogram (EKG) was also monitored.

2. Inflation Bottle Evaluation - Ocean Simulation Facility (OSF)

The suit inflation bottle was tested in the NEDU Ocean Simulation Facility (OSF). It is a hyperbaric facility with multiple dry chambers interconnected with a wet diving chamber capable of simulating deep diving with heliox. Heliox bounce dives to 300 fsw were conducted in accordance with Annex A to test the capacity of the suit inflation bottle.

## D. PHYSICAL VARIABLES

1. Termination Criteria

The following conditions were specified as conditions for termination of the dive:

a. Rectal temperature below 35°C at any time during the dive.

b. A digit (finger or toe) temperature that attained 8°C for longer than 30 minutes or 6°C at any time, the 6/8 criterion.

c. The fraction of the inspired carbon dioxide ($CO_2$) ($F_ICO_2$) greater than 1.5% SEV from the inhalation hose.

d. $O_2$ bottle pressure less than 350 pounds per square inch gauge (psig).

e. Diver may terminate at any point in the dive for discomfort, pain or any other reason.

2. Risk/Benefit

The divers were subjected to the risks associated with cold MK 16 diving which include caustic cocktail, drowning, gas embolism, hypothermia, nonfreezing cold injury, hypoxia and $CO_2$ intoxication. The result of this study provided a table of safe exposure limits for diving in cold water with the MK 1 MOD O dry suit that will enable dive supervisors to plan dives with a reduced risk of cold injuries.

## E. THERMAL MEASUREMENT

1. Temperature Measurement

Esophageal temperature could not be measured due to diver ear squeeze. The esophageal probe interfered with the diver's ability to pinch closed their nostrils in the full face mask when equalizing their middle ear space. Therefore, monitoring of the core temperature was performed with rectal temperatures. All thermistors were accurate to within $\pm$ 0.1°C when compared to a calibrated quartz thermometer (model: 2804AT, Hewlett-Packard Model, CA) with module probe (model: 2120A-60946, Hewlett-Packard, CA). The calibrating thermometer was traceable to the National Bureau of Standards for accuracy.

a. Rectal Temperature. Rectal temperature was obtained by using an external rectal probe (model: 400, Yellow Springs Instrument, Yellow Springs, OH) placed 15 cm into the rectum and taped in place.

b. Extremity Temperature. Fingertip and toe temperatures were obtained with small thermistors (model: 44033, Yellow Springs Instruments, Yellow Springs, OH) modified with extra electrical insulation to provide strain relief. The thermistors were taped in place under the nail edge of the first/third/fifth digits of both hands and first/fifth digits of both feet for a total of 10 digit locations. Particular care was taken not to restrict circulation when taping these thermistors in place.

## F. DATA ANALYSIS

Data from temperature sensors and oxygen bottle pressure were taken every 30 seconds on the DMS. The mean ± standard deviation (SD) was calculated for extremity temperatures.

## G. PROTOCOL

### 1. General Overview

This dive series utilized the same eight subjects for dives at the three temperatures studied. The same dry suit configuration was worn throughout the dive series after the initial modifications were made.

Two divers were instrumented, as described above, one hour prior to dressing. This allowed for proper placement of EKG, extremity temperature, and rectal temperature sensors before covering them with the polypropylene diver's skins. Simultaneously, tenders prepared the MK 16 UBA and performed the necessary pre-dive checks. Data processing personnel conducted the necessary systems checks to ensure accurate and timely recording of data. The standby SCUBA diver dressed in full 1/4-inch wet suit with hood.

When the above mentioned procedures were completed, the divers and tenders assembled. A daily briefing was conducted and the expeditious dressing of the divers was performed, limiting the heat stress experienced by the divers. To enhance the divers' comfort while dressing, the divers' faces were kept wet and a fan was used to increase evaporation which limited sweating. The divers then entered the pool, performed their in-water checks and adjusted air to the dry suit to ensure neutral buoyancy. The divers descended to the bottom of the pool and added air to their dry suits to maintain the same level of buoyancy they had obtained on the surface. They remained on the bottom at rest for 300 minutes or until a termination criteria was met. They were instructed to immediately report leakage, numbness or pain.

2. Dive Day

| Time | Activity |
|---|---|
| 0600 | Instrument diver with DMS and dress into the PTS. |
| 0730 | Divers enter the water. Baseline physiological and MK-16 measurements are recorded after 10 minutes of immersion. |
| 0800 | Descend to the bottom of the pool, purge MK 16. |
| 1300 | Terminate the dive. |
| 1300 | Divers rewarm as needed, drink, and eat. |
| 1500 | Medically evaluate all divers before releasing to go home. |

## H. DIVER SAFETY

$CO_2$ was routinely measured by sampling 1 liter of the gas from the inhalation hose. Sampling was scheduled hourly and increased to every 15 minutes if any $CO_2$ was detected over 0.2% surface equivalent (SEV) threshold. The dive was aborted if the $F_ICO_2$ rose above 1.5% SEV.

Additionally, divers' cardiac function was measured via EKG throughout their exposure. A hot water bath (104°F) was available for rewarming. Drills were conducted prior to actual diving to simulate various casualties. They included caustic cocktail, gas embolism, near-drowning and cardiac arrest. A recompression chamber was aligned in standby condition with chamber personnel available within 5 minutes of alarm.

A physician trained in diving madicine remained on dive station during all dives. He monitored the signals the technician was receiving on the DMS and maintained close communications with the divers and dive supervisor.

This study was reviewed and approved by the NEDU Review Committee for the Protection of Diver-Subjects.

# III. RESULTS

## A. DRY SUIT EVALUATION - TEST POOL

### 1. Thermal Exposure Limits

The termination times in minutes are found in table 2. These were based on the time needed once the diver entered the water until his extremities reached the previously described termination criteria. Although rectal temperature was carefully monitored, the extremity temperatures, fingertip and toe, reached their termination criteria before the core temperature did in all cases where the dry suit did not leak and, therefore, was the basis for termination of the dive. All dry dives terminated due to extremity (ext) termination criteria vice core temperature drop. A dive was considered dry when no water could be wrung from the undergarment upon surfacing. Nearly one out of every three dives terminated prematurely because of dry suit flooding. Table 2 reflects only those dives where the diver remained dry. One dive terminated due to core temperature drop when the diver's suit slowly flooded through the dump valve over the course of the dive . Core temperature remained above 36°C in all other dives. Figure 1 depicts extremity temperature trends. The individual digit that terminated the dive was plotted as were average feet and hand temperatures.

## TABLE 2

**DURATIONS FOR DRY THERMAL EXPOSURES AT THREE NEAR FREEZING *TEMPERATURES FOR THE MK 1 MOD 0* (MODIFIED*) DRY SUIT**

| | 2°C | | 4.5°C | | 7°C | |
|---|---|---|---|---|---|---|
| Diver # | EXT | Time (min) | EXT | Time (min) | EXT | Time (min) |
| 1 | LH | 51 | LH | 180 | (4) | 300 |
| 2 | LH | 77 | LH | 149 | (4) | 300 (1) |
| 3 | LH | 42 | RH | 67 | RF | 232 (5) |
| 4 | RH | 38 | RH | 63 | (2) | (2) |
| 5 | RH | 45 | (2) | (2) | (4) | 300 |
| 6 | RF | 114 | RH | 151 | RH | 296 |
| 7 | (2) | (2) | LH | 94 | (4) | 300 |
| 8 | LF | 75 | RF | 128(3) | (2) | (2) |
| Average | | 63.1 | | 118.9 | | (6) |
| Standard Deviation | | 27.3 | | 45.1 | | (6) |

Extremity (EXT) designations: L-left, R-right, H-hand and F-foot

(1) The diver completed the full 300 minutes but core temperature was 35.7°C at termination due to slow leakage around neck dam.

(2) No dry dive was obtained for this diver at this temperature.

(3) Diver #9 returns from knee surgery to complete this dive.

(4) These dives completed the full 300-minute mission profile without reaching the *extremity termination criteria.*

(5) Diver 3's right foot failed on a second dive in 205 minutes at this water temperature. His foot insert was damp on inspection.

(6) All dives that remained dry were able to satisy the 5-hour mission requirement at this temperature.

* A (modified) dry suit had a velcro strap added to the weight vest, modified urinary overboard dump system, and a Viking glove substitution.

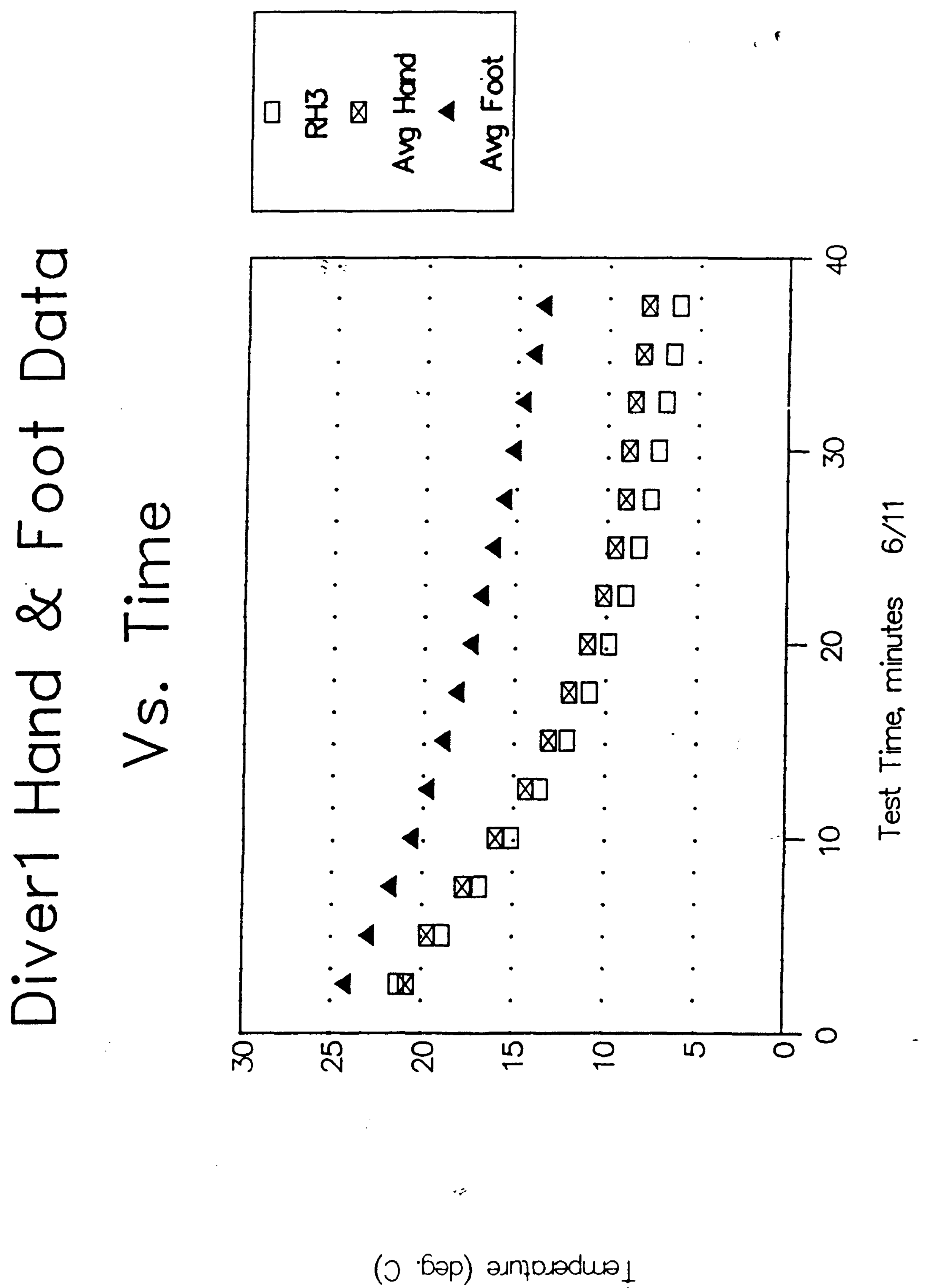
Diver1 Hand & Foot Data
Vs. Time
RH3
Avg Hand
Avg Foot
Temperature (deg. C)
30
25
20
15
10
5
0
0
10
20
30
40
Test Time, minutes 6/11

FIGURE 1

## B. INFLATION BOTTLE EVALUATION - OSF

1. The results of the manned dives to 300 fsw to determine inflation bottle requirements are listed in Table 3.

### TABLE 3

### ACTUAL VOLUME OF AIR AT 1 ATMOSPHERE REQUIRED FOR 300 FSW AT 20$^{o}$C FOR THE EOD MK 1 MOD 0

| BOTTLE TYPE | STARTING PRESSURE (psi) | FINISHING PRESSURE (psi) | VOLUMES LITERS | VOLUMES CUBIC FEET |
|---|---|---|---|---|
| Inconel | 3517 | 209 | 161.6 | 5.7 |
| Inconel | 3493 | 131 | 164.2 | 5.8 |
| MK 15 | 2532 | 1251 | 250.0 | 8.8* |
| MK 15 | 3439 | 2392 | 204.3 | 7.2 |

*Largest diver used a medium tall vs. medium regular dry suit

2. Assuming constant temperature, 300 fsw is equivalent to 133.5 psi (on the surface (1 ATA)). Accordingly, an "empty bottle" at depth (300 fsw) will have 133.5 psi on the surface. At depth both divers with inconel bottles reported a mild degree of increased suit squeeze, a decrease in buoyancy, and lack of additional gas reserve from the suit inflation bottle. Both divers using MK 15 flasks as suit inflation bottles achieved 300 fsw with adequate reserve.

All suit inflation bottles performed without free flowing or leaking. Bottle location was a concern. Divers stated that the bottle would be easily fouled during an open-water dive when laterally positioned on the leg. However, such placement allowed the diver to quickly secure the bottle if the add button failed in the open position. Attachment to the base of the MK 16 was the desired location if an adequate shut off system is provided. All divers felt that a means to quickly secure the bottle in the event the air fill button fails to shut is imperative. The consequences of becoming uncontrollably positive buoyant at depth can be catastrophic.

3. Only the two divers with the MK 15 flasks had adequate gas volume to keep their suits inflated to 300 fsw. The average volume of gas required by these two divers was 8.0 cubic feet.

## C. HUMAN FACTORS RESULTS

A questionnaire was given to the divers during the final week of the dive series to record their comments. Only those responses that were registered by at least 75% of the test divers were recorded. A consolidation of their remarks and opinions by individual component follows:

1. AGA Full Face Mask (FFM)

All divers unanimously agreed that the FFM was the preferred method of face protection. Additionally, it provides a means of communication, has a quick-disconnect switchover capability and eliminates the need for the mouthpiece. Elimination of the mouthpiece with a dry FFM will prevent drowning should the diver become unconscious or experience a seizure in the water.

Jaw fatigue due to pressure on the mandible from the FFM was a universal complaint. A tight fitting mask is essential in closed circuit scuba to avoid loss of gas through a leaking face seal. Bubbles leaking past the face seal are clearly unacceptable in a mine countermeasure environment. A silicon version of the face mask seems to lessen but not eliminate this problem. Addition of the hood provided a rubber seal allowing the FFM to form a seal that did not leak. Weights added to the lateral aspect of the mask decreased fatigue of the neck muscles on long duration dives. These muscles worked against the buoyant force of the mask throughout the dive. The switchover lever should be in the vertical position for closed circuit and the horizontal position for open circuit. This will facilitate finding the lever in an emergency requiring the switch to open circuit.

2. Dry Suit Dump Valve

The divers felt it was in a good location, being easy to activate should an overinflation of the dry suit occur. Leakage was experienced by all divers throughout the study regardless of use during the dive. A theory was advanced that the valve's differential pressure is increased by a valve placed lower on the diver, since the valve had been moved from the chest to the forearm. With the same pressure maintained throughout the suit and increased water pressure at the lower position, the valve would be more apt to leak. No diver reported being in a position where the forearm was maintained lower than the chest during the course of the dive, therefore undermining the theory that a lower differential pressure across the valve caused the problem. A Versipore fabric patch was inserted into the valve itself. Versipore has the unique property of allowing gas but not liquid to pass through its selective material. Unfortunately, it had questionable merit since some leakage was noted with this patch in place. The degree of flow impairment when dumping gas from the suit through this patch requires further study.

3. Suit Inflation Bottle

The divers wanted the bottle mounted on the leg despite acknowledgment that it got in their way and easily fouled. A major concern was the ability to quickly secure the bottle's valve should the suit inflation button fail to close. This is an emergency that has been reported on operational dives. If an easily accessible cut-off valve could be provided near the fill button, the divers would prefer the bottle stowed behind them out of the way.

4. Gloves

Without any question, all divers emphatically disapproved of the DUI dry suit glove. They all agreed that the Viking glove was clearly superior and provided the basic requirement of keeping the hands dry. They agreed that the three fingered glove was the optimum arrangement taking into account dexterity versus thermal protection.

5. Hood

An attached latex hood was used only during the work up dives.The divers all stated that the dry permanently affixed hood was desired on any long, cold dive. They felt it greatly added to diver comfort especially in the posterior aspect of the neck and head. In addition, it added another barrier to the neck dam to keep out water.

6. Urinary Overboard Dump System

The divers preferred the Freedom condom catheter for comfort and its ability to remain attached throughout the dive. The original tubing was redundant and was shortened to suit the individual diver, thus avoiding kinking. One-way valves were installed to prevent water leakage around the catheter. Despite these modifications, several divers complained of uncomfortable back pressure when attempting to urinate. This discomfort was lessened with diver training. Some systems have eliminated the one way valve and use a rubber cap to secure the tube externally after each use. Although this relieves some of the flow resistance, the risk of dry suit flooding is increased. A method to equalize the pressure inside the tube is needed.

7. Thinsulate, M-400

This study simulated a decompression scenario with no work or swimming. Despite this, the two piece ensemble shifted even with minimal activity. The divers reported that in past experience, activity has caused two piece ensembles to shift during the course of the dive and leave areas of the trunk unprotected. A one piece thinsulate undergarment is preferred to prevent such shifts.

8. Weight Vest

The loose lead shot used to weight the divers was unsatisfactory. Divers would have preferred lead shot packets for two reasons. First, the packets provided an efficient method to properly weight individual divers. Second, the loose lead shot constantly fell out despite meticulous efforts, under ideal laboratory conditions.

9. Termination Criteria

Divers all felt that the investigator's involuntary termination of the dive was appropriate despite the fact the durations fell considerably shorter than the desired of 5 hours. The study's extremity termination criteria closely reflected the point where these divers stated they would have aborted an operational dive if decompression was not required.

10. Decompression Posture

Divers stated that actual decompression posture should entail attachment to the lazy shot, fins off, suit inflated with additional gas and both hands above or at the head level. These measures should lessen the thermal stress and make the decompression more comfortable to the diver.

11. Leak Testing

Prescribed methods for testing the suit did not detect all leakage prior to actual diving. The use of a manned dip test with full length, light colored (khaki) clothing was extremely useful in detecting additional leaks. This test used the same individual that was to dive that suit and therefore was more sensitive than the standard test. Although time consuming, this test is recommended when a long duration dive in cold water is planned. This additional test can not guarantee watertight integrity for the dive. New leakage sites could result from redressing or during the course of the dive.

12. MK 1 MOD 0 Dry Suit- General Opinion

At the conclusion of the study, every member of the dive team had extremely negative comments about the subject suit's operational usefulness.

All divers felt, that despite its design, assistance is still needed to don the suit. Divers all had negative feelings about diving it for long durations in cold water that involved decompression obligations. All stated they have used more dependable dry suits.

All the divers stated they normally dive rubber dry suits when the need arises. They felt its ruggedness, flexibility, and watertight integrity provided a clear advantage over the MK 1 MOD 0 dry suit.

## IV. DISCUSSION

### A. GENERAL

This evaluation was based on the simulation of an MK 16 working dive to 300 fsw in near freezing water. The decompression time for a 270 fsw dive for 25 minutes was the basis of the target duration of 5 hours, since it is the longest in-water time dive that is not an exceptional exposure. The presently accepted termination criteria makes it virtually impossible for any passive thermal system to safely complete this exposure [9]. Suggestions in the past have recommended massive additions of insulation, which in effect amounts to encasing the diver in a mass of neoprene and weighting him with a clump. This is obviously unsatisfactory, especially for EOD divers whose precision work depends on a high degree of mobility and hand dexterity.

Acknowledging that no passive dry suit may perform this mission, this manned evaluation determined passive thermal capabilities of the MK 1 MOD 0 dry suit at near-freezing temperatures. A basic point needs to be emphasized when dealing with dry suits. <u>A dry suit needs to be dry</u>. The amount of insulation provided by a thin layer of dry suit fabric is small in comparison to the thermal protection afforded by the air trapped in the dry undergarments. When these undergarments become wet, a dramatic decrease in the suits overall insulation occurs. The stage is set for a hypothermic emergency if the diver remains in the water. The EOD 300 fsw mission scenario is radically different from other dry suit diving. When dry suits are used, minimal in-water decompression is planned or else hot water suits are used. If the diver gets wet he merely aborts the dive, performs his decompression, exits the water and rewarms. The EOD diver will not have that option with a 5 hour-obligated cold water exposure. <u>His dry suit must remain dry.</u>

## B. DRY SUIT EVALUATION

### 1. <u>Control of Variables</u>

a. <u>Suit Modification</u>. After the original modifications to the glove system, the urinary dump system and weight belt, no deviation from the configuration of the dry suit was allowed. This eliminated variability in thermal protection if diver's preference was a option.

b. <u>Hand Position</u>. The divers were required to keep their hands below the shoulders and were not allowed to overinflate their gloves to increase its insulation. However, the actual position of the hands shifted according to the divers' preferences which is the method used during operational dives. The divers were reminded that they were free to change hand position if any discomfort was experienced.

c. Suit Inflation. The divers were reminded to maintain the same level of buoyancy on the bottom that they had on the surface by adding the proper amount of gas to the suit. Maintaining this same level controlled the variability in thermal protection due to excessive suit squeeze or overinflation.

d. Heliox Gas Temperature. This thermal evaluation was not conducted at depths greater than 15 fsw. Helium has a greater thermal conductivity than nitrogen and this effect is accentuated at depth due to an increase in the gas density. This condition will have the most dramatic effect on core temperature. Fortunately, the majority of the dive time is conducted at the shallower depths during decompression. Also, the inhalation temperature of the gas is unknown. The heat exchange when the warm moist exhalation gas from the diver traveling through the cold exhalation tube to the warm absorbent bed to the cold inhalation tube may minimize the impact on the respiratory heat loss of the diver.

e. Dive Station Temperature Control. The actual study was conducted under ambient temperatures of the dive station between 80-90 °F. Dressing procedures were aimed to keep the divers comfortable and minimize their actual exposure to these warm ambient temperatures. Any sweating or superficial vasodilatation of the skin by the diver on the surface would increase the diver's heat loss by impairing the system's insulating properties and increase the thermal gradient respectively. Consequently, core temperature would be most effected.

f. Suit Inflation. A procedure for correctly filling the dry suit with air was stressed. It entailed raising one arm above the head and adding air until it filled the sleeve to the mid forearm. Weighting was adjusted to keep the buoyancy of the diver at a point where the face mask was awash on the surface.

g. Buoyancy Control. Buoyancy adjustment was difficult due to the weight belt's use of pellets versus self-contained packets for weighting. Changing the weighting for individual divers was difficult since a convenient method of quantifying the amount of weight used for each diver could not be recorded for subsequent dives. The procedure to fill one sleeve of the dry suit with air midway on the elbow with the face mask awash was stressed. This same criteria was used to fill the suit on the bottom in an attempt to maintain the same level of suit squeeze in each dive.

h. Convective Heat Loss. Evaluation was conducted in a test pool without current. This eliminated a major source of convective heat loss. It has been estimated that a 3-4 fold increase in heat loss is observed if the current is increased to 0.5 m/s (1 knot) [8]. Marked increases in convective heat loss can be demonstrated by the movement of the body while shivering. Additional factors such as vasoconstriction, artery-vein heat exchange, differences in the body's heat stores and the deformation of the body's surface are a few of the factors that make the data of human exposure to cold notoriously variable [8].

2. Leakage

Dry suit leakage continually plagued the evaluation, especially through the gloves, valves, neck dam, and urinary overboard dump system. Initial modifications as previously described curtailed most of the leakage but not all. The remaining leaks were confined mostly to the valves. Since extremity temperature criteria terminated the dives before core temperature became a factor, these leaks will adversely impact core temperature when a method to keep the extremities warm and longer durations are attempted.

3. Contaminated Water Protection

Diving in water contaminated by chemical or biologic hazards is a serious risk to the diver. Rubber has been shown to be more effective against penetration by chemical contaminant when compared to neoprene [10]. In addition, foam neoprene is more difficult to decontaminate than rubber especially for biologic contaminants [11].

When calculating the insulation that a dry suit provides, only the insulative value of the undergarments is used [9]. The contribution from the dry suit is minimal whether it is neoprene or rubber. However, the degree of difference between these two materials may be a factor when using the dry suit as a protective garment in warm water. It would add to thermal heat stress if this diver needed the dry suit to dive in warm contaminated water.

## C. DRY SUIT INFLATION BOTTLE

### 1. Background.

A single prototype inconel bottle was provided for this evaluation. This inconel bottle was to replace the original aluminum bottle that had proven to be inadequate for dives to 300 fsw. This evaluation found the inconel bottle also inadequate. However, the actual volume required was determined.

### 2. Variables

a. Four dives to 300 fsw were conducted. The dry suit with its required undergarments were worn. Two dives were conducted with the inconel bottle and two with an MK 15 flask. The two most experienced dry suit divers were given the inconel bottle. Only divers fitted with medium sized dry suits were used. A single, continuous descent at 75 feet per minute in the OSF was maintained. The intent was to test the inconel bottle's ability to meet its mission requirement of 300 fsw under the most ideal laboratory conditions. This evaluation proved that the bottle failed in the optimum situation and is therefore operationally unacceptable.

b. Testing was performed using pre- and post-test bottle pressures equilibrated at 20°C. This introduces a maximum error of 7% in the volume calculation since the decrease in the bottle pressure is directly related to the change in temperature of an ideal gas. This relationship is described:

$$\frac{P1*V1}{T1} = \frac{P2*V2}{T2}$$

$$\frac{P1}{P2} = \frac{T1*V2}{T2*V1} = \frac{T1}{T2}$$

Since the volume (V) of the flask remains the constant for all practical purposes, then:

$$\frac{P1}{P2} = \frac{273+20}{273} = \frac{293}{273}$$

$$= 1.07$$

This 7% change due to the chilling of the gas at 0°C may be partially negated by the body warming the gas when it enters the dry suit. The degree of rewarming can only be speculated with the worse case of no rewarming resulting in the full 7% reduction in bottle capacity when diving in 0°C water.

3. Dry suit Inflation bottle

A larger dry suit inflation bottle is needed. The evaluation was conducted with four divers. The inconel bottle was a prototype engineered to hold adequate volume after previous testing proved the aluminum bottle inadequate [2]. The prototype inconel bottle also failed to provide adequate volume for a medium-sized diver to descend to 300 fsw without a squeeze. This left nothing for later in the dive when additional gas might be needed for make up gas or during decompression for insulation. The divers using the MK 15 flask used an average of 8 cubic feet of gas. A reserve of 40% is recommended. This would require 11-12 standard cubic feet (SCP).

An auxiliary bottle as described in Annex B has been recommended by Special Warfare units. They have secured this bottle under the MK 15 UBA. This larger bottle provides additional dividends when it is equipped with a first stage regulator with 3 low pressure air hoses to the following:

a. MK 4 life vest.

b. Dry suit

c. NCSC quick disconnect for the FFM.

The third hose to the quick disconnect would allow the quick disconnect from the FFM to remain connected throughout the dive for additional protection of the fitting. But most importantly, it provides a completely independent breathing source in an emergency.

## V. CONCLUSIONS

The EOD MK 1 MOD 0 dry suit performed unsatisfactorily in the original configuration. The thermal protection as originally configured was limited and could only be used under the guidelines used for a wet suit. Nearly all of the changes required addressed the basic lack of watertight integrity encountered during the initial dives. Water leaked by the neck dam, glove seals, suit penetrators, and valves. The subsequent wetting of the dry suit undergarments markedly compromised the thermal protection for which the system was designed. Any safe exposure limits based on these "wet" exposures would not have accurately described the system. Only a qualitative rating of unacceptable can be provided.

NAVSEA 06X directed modification to the issued dry suit in an effort to minimize leakage and other identified problem areas as noted. After these modifications were affected, divers were able to remain relatively dry, but the safe exposure time limitation was reached well before the decompression obligation limits of deep dives would be completed. Only those changes that were absolutely necessary to enable the completion of the evaluation were made. These changes are outlined below.

### A. MODIFICATIONS MADE TO THE PASSIVE THERMAL SYSTEM

1. The Viking three-fingered modified dry suit glove replaced the DUI dry suit glove. The Viking wrist seal provided a consistently watertight connection between glove and wrist seal. In addition, no relief valve was required on the Viking glove which eliminated another portal of entry for water. The Viking gloves kept the hands dry throughout the evaluation. Their implementation was the most important modification to the PTS. The Viking soft rubber apron proved superior to the DUI hard plastic double O-ring method for glove attachment. The actual glove is made by Cytec and is now reportedly available to DUI as well as Viking.

2. The leaking experienced at the suit's valves requires investigation. It must be determined if leaking occurs around and/or through the valves.

3. The urinary overboard dump system leaked into the suit when the diver relieved himself despite all connections between the diver and the suit penetration being assembled as designed. Shortening of the plastic tubing to the suit penetration greatly relieved this problem. The leaking occurred when the soft plastic tubing connecting the condom catheter to the suit penetrator kinked. This caused a painful back pressure with urine leaking around the condom catheter and into the suit. Again, the most important feature of a dry suit is its ability to keep the diver dry. It makes little difference whether the moisture is water, sweat, or urine. The potentially fatal effects of core hypothermia are increased in a wet dry suit.

With females entering the diving profession, a method for urine elimination needs to be devised. No effective method for female diver urine elimination has been developed which eliminates the large area of damp cold material against her trunk. Appliances are available that have the potential for making the female compatible with the modified urinary overboard dump system used by the male, but is not recommended. This significant collection of moisture against the female trunk over a 5-hour dive would lead to potentially life threatening hypothermic exposure. Accordingly, this should be avoided until an adequate system is developed.

4. The weight belt required the addition of a velcro strap applied perpendicularly to the shoulder straps on the chest. This modification better secured the weight belt to the diver and increased his overall comfort.

5. Leakage was such a recurrent problem that a pre-dive manned leak test was performed. Prior to a dive, each dry suit was tested by the diver wearing a full length khaki uniform as the undergarment. He was submerged to the neck level for 10 minutes in water and brought to the dive station and undressed. The lighter khaki fabric readily displayed any area of water leakage when the diver was examined without the dry suit. Any leak was either corrected or a new dry suit was used. This test was in addition to the testing prescribed by the dry suit manual [12]. Leaks in the overboard dump valve and suit inflation valve were lessened with considerable attention to the suit penetrations but they were never stopped. It must be emphasized that additional design is needed to make these penetrations watertight. These valves have reportedly been used without problems for years. The only difference in their construction is the substitution of beryllium for the

steel components. A potential cause may be a change in the beryllium spring's elasticity over time when compared to the original steel spring.

One concern about the placement of the valve on the sleeve is that it increases the valve's exposure to silt when working on the sea floor. Operational evaluation must include diving in a silty environment to ensure that the valve does not foul and remain partially open.

## B. PROPOSED CHANGES

1. A hood could be attached to the dry suit. The hood should be used on longer and deeper dives for both diver comfort, extra leak protection at the neck, and increased thermal protection. The hood was only used during the work-up dives. The detached, wet, neoprene hood was used during the test dives.

2. The prototype inconel bottle contained only enough gas volume for experienced, medium sized divers to descend one time to 300 fsw at 75 ft per minute. Both divers experienced a mild suit squeeze and required additional volume to optimally fill their suits at depth. The two divers who were afforded the opportunity to use exactly the required volume of gas used between 7.2 - 8.8 cubic feet to reach 300 fsw. Sound engineering design would plan for a bottle capacity of 10-12 cubic feet to provide an adequate reserve. Note that this dive was done with experienced, medium-sized dry suit divers on a single controlled descent under ideal laboratory conditions. The volume requirement used in operational dives could be increased due to factors such as a larger diver, a poor dry suit fit (diver wearing a dry suit that is too large), gas adjustments to the suit throughout the dive due to excursions, inflation gas leaks, additional suit inflation during decompression to increase insulation and colder ambient temperatures decreasing the volume actually available.

Recommend the largest bottle that can be safely affixed under the MK 16 UBA. If designed properly, it could provide more than enough gas for the suit while providing an emergency breathing source via the quick disconnect. Access to both the oxygen, diluent bottle and dry suit bottle valves must be assured. Special warfare divers have proposed such a system for use with the MK 15, since it requires no additional equipment or hoses than presently used. It employs an auxiliary bottle. See annex B for details.

3. The diver's ability to respond to cold water exposure can be enhanced by the following measures:

a. An increase in his basal metabolic rate provides more heat production. This can be achieved by requiring regular intense physical training.

b. Regular cold exposures have been shown to increase the effectiveness of body's means of conserving heat. For instance, the body's ability to vasoconstrict superficial blood vessels when exposed to cold has been shown to be faster in those given repeated cold exposures and therefore providing an important protective effect [8]. Teams planning to dive in near-freezing water should train regularly to gain any additional protection from this physiologic effect.

4. Medical research of compounds in the class of dinitrophenol need to be investigated as a possible means to physiologically maintain core temperature by a more efficient method besides shivering. This compound essentially uncouples the mechanical effort that is wasted in order to produce heat by the individual cells [13].

5. Pursue methods of active warming of the divers. At the minimum, active heating of the hands and feet will be necessary. Since the need for warming will be primarily required when the diver is decompressing instead of swimming freely, the problem is greatly simplified. Several methods warrant future investigation:

a. Use electrically heated gloves and socks. A complete system was tested at NMRI that allowed 5-hour durations [14].

b. Investigate radio frequency (RF) rewarming. A prototype system is being developed at NAMI, Pensacola Fla. Early results are promising [15].

c. Investigate advanced Catalytic Combustion Technology (ACCT). A portable heater that will supply adequate hot water to the diver is being developed at DCIEM.

d. Utilize a CONOX heater. A heater was developed for special warfare. It could be utilized as a heat source for a container that would hold warm water in which the diver could keep his hands and feet.

e. Utilize a tube suit with heat pump. A system is under development by Naval Coastal Systems Center which employs a heat pump that provides warm water to a closed tube suit arrangement.

## C. SUMMARY

This evaluation was disappointing due to the unacceptably high incidence of leakage. The study was initially intended to quantify the thermal characteristics of the EOD MK 1 MOD O passive thermal protection system. Instead, it was a frustrating problem of damage control to manage this dry suit's lack of *watertight integrity*. This study clearly shows the need for an ongoing human factors/operational evaluation of candidate dry suits so that inferior dry suits never get to the level of attention this dry suit has received.

Water has 1000 times the specific heat of air. The thermal conductivity is 25 times greater. This clearly shows the need for a dry suit that remains dry. In addition, adequate gas must be available to prevent a painful suit squeeze but also to prevent compression of the PTS. Compression can decrease the insulating properties by over 30% [16].

<u>SCUBA diving to 300 fsw is the most arduous diving that the Navy plans to conduct.</u> Its planning and emergency contingencies must be clearly laid out and executed if this evolution is to be conducted safely. This evaluation addressed the life threatening thermal stress to which these divers will be exposed. Such operational dives must be properly planned and executed to ensure diver safety. With the present equipment divers may be obligated to remain in near freezing water for up to 5 hours at rest. This means that the dive will be conducted without active heating, with minimal surface control, without a

means to monitor diver core temperature, and operating from a rubber raft. There is no room for error.

## VI. RECOMMENDATIONS

1. The following changes are required before the EOD MK 1 MOD 0 dry suit would be marginally acceptable:

a. Replace the gloves with the modified gloves available through Viking. DUI reportedly supplies these modified gloves now.

b. Leak check all dry suits fully assembled. Particular attention is required around any suit penetration. A manned dip test of the khaki clad diver is recommended.

c. Shorten the urinary overboard dump drainage tube to prevent its kinking during operation. Use the Freedom Condom Catheter.

2. With the above changes, the following thermal exposure limits are recommended for this dry suit if it is intact and dry during the exposure. These durations were based on the average times for test dive termination. It should be noted that at 35°F and 40°F the EOD MK 1 MOD O dry suit failed to complete the mission duration of 5 hours.

| Temperature (°C) | Temperature (°F) | Duration (min) |
|---|---|---|
| 2 | 35 | 60 |
| 4.5 | 40 | 120 |
| 7 | 45 | 300 |

3. Active heating, particularly the extremities, is recommended below 7°C (45°F) to obtain a 5-hour duration.

4. Investigate and correct the leakage at the overboard gas dump valves.

5. Affix a permanent latex hood to the dry suit.

6. Use packets of shot in the weight vest. Add a chest strap to the weight vest.

7. All further dry suit evaluations begin with an operational diver series to ensure it's watertight integrity prior to detailed investigation.

8. Increase the suit inflation bottle to at least 8 SCF. A reasonable reserve would require a bottle with a 10-12 SCF capacity.

Even with the improvements, this PTS performed marginally. Its watertight integrity can not be guaranteed. Further operational use requires serious reconsideration. Even after modification this suit will not meet the 5-hour mission requirements in water below $7^{o}C$.

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# APPENDIX A

## INFLATION BOTTLE TESTING

### A. INTRODUCTION

The capacity of the improved inconel suit inflation bottle was evaluated to determine if it contained an adequate volume of gas to get the diver to 300 fsw without suit squeeze. Previous experience reportedly found the 1800 pounds per square inch, gauge (psig) aluminum bottle to be an inadequate source of gas to fill the suit, but no quantitative measurement concerning the actual volume requirements was determined. A 0.718 liter, high pressure inconel bottle was developed that contained a larger volume.

### B. METHODS

The test consisted of two sets of two divers dressed in the EOD MK 1 MOD O drysuit wearing the same ensemble of undergarments described for the thermal evaluations in the test pool. The only difference was that no physiologic monitoring was conducted during these bounce dives. One diver wore the new inconel bottle while the other diver's suit inflation whip was connected to a MK 15 gas flask (Biomarine, Tampa FL) whose floodable volume was 2868 ml and filled with air to 2500 psi. This afforded over three times the volume that the inconel bottle provided. Only the MK 15 bottle was instrumented with a pressure transducer (Druck, INC. model PTX-160/D1, Newfairdield, CT) with accuracy reported to $\pm$ 0.1% full scale deflection. This provided real time measurement of the bottle pressure as the diver added air to his suit on descent. The diver with the inconel bottle was provided with a second full bottle. During the compression, if that diver signaled that he had depleted his installed bottle, descent could be temporarily halted and the bottles interchanged. In that case, the inconel bottle would be considered inadequate but descent would continue to 300 fsw. This would allow for later determination of the required volume. Real time pressure profiles from the MK 15 bottle were recorded on both the PC based data acquisition system as well as the Gould strip chart recorder. Both the pre- and post-bottle pressures were obtained with a Druck pressure transducer after the bottle remained in a temperature regulated room for over one hour to allow equilibration.

Heliox surface supplied diving with the AGA full face mask (FFM) was used instead of the MK 16. The chamber was compressed with air while the tenders breathed from the

Built-in Breathing System (BIBS) throughout the dive. Decompression was conducted in the dry chamber in accordance with the Navy Diving Manual.

In order to minimize the variability in suit inflation, specific measures were taken. First, only divers who fit the medium sized dry suit were used who were experienced in drysuit diving. Secondly, the diver adjusted his weighting on the surface of the wet pot to attain neutral buoyancy with the manufacturer's recommended gas volume added to the suit as described earlier. The divers then descended to the bottom of the wet pot and added gas to the suit to gain the same level of neutral buoyancy. Once suit inflation and in-water checks were completed, the complex was compressed at 75 feet per minute. The divers added gas to maintain the same level of buoyancy and suit squeeze throughout compression. Upon reaching 300 fsw, the divers were instructed to add further gas as necessary before ascent commenced. Before ascent , the bottles were secured.

## C. INFLATION BOTTLE CALCULATIONS

1. Calculation of required volume at one atmosphere:

   a. Variables

Bottle pressures recorded at 20°C
Inconel floodable volume ?.718 liters
Mk 15 flask floodable volume 2.868 liters

   b. Equation

Volume is calculated by the following:

$$V = (P_O - P_1) * \frac{1 \text{ atmosphere}}{14.7 \text{ psi}} * V_b * \frac{\text{cubic foot}}{28.3 \text{ liters}}$$

V - calculated volume at one atmosphere
$P_O$ - starting bottle pressure (psi)
$P_1$ - finishing bottle pressure (psi)
$V_b$ - floodable bottle volume (liters)

## APPENDIX B

### THE AUXILIARY SUIT INFLATION BOTTLE

A modification was proposed by Navy Special Warfare divers. They installed the suit inflation auxiliary bottle under the MK 15. The bottle was secured with two stainless steel bands. The bottle had a first stage regulator with three low pressure ports. These low pressure ports were connected via a low pressure hose to the following:

1. A back-up second stage regulator or directly to the AGA full face mask via a quick disconnect.

2. Life vest auto-inflator.

3. Dry suit

The entire system would require one additional low pressure hose for the life vest, if desired.

Advantages:

1. Provide an emergency breathing system for a catastrophic rig failure

2. Provide more than the required volume of gas to the suit for inflation

3. Provide gas to the life vest for inflation.

4. Suit inflation bottle stowage (conveniently out of the way if attached beneath the UBA).

Nukols conducted an engineering analysis of the PTS and found 20-cubic feet to be the minimum volume of gas required in the high pressure storage flask. He also recommended purging of the dry suit at depth to eliminate helium that has entered the suit transcutaneously by isobaric counterdiffusion (17). Any helium diffusion into the dry suit decreases the overall PTS insulation with time. The MK 15/16 flask is an alternative bottle that has an adequate volume and low magnetic signature.

Disadvantages:

1. Authorization to modify the rig would be required.

2. Need to insure accessibility to diluent and the suit inflation bottle valves.

3. Deepest depth of emergency air breathing would need to be determined.

4. Would require the diver to disconnect from the bottle prior to connecting with the EBS.

5. Bottle requirement for low magnetic signature.

Emergency Breathing System Type II (EBS II) Special Consideration:

The EBS has a requirement to deliver air to a diver who has experienced a rig failure (18). It also has the requirement to remain as small and light as possible.

A proposed solution would be the use of an extremely lightweight low pressure umbilical/reel assembly that attaches directly via a quick disconnect to this large auxiliary suit inflation bottle vice the full face mask (FFM). The bottle would be serving as a volume tank. Since the diver's FFM would already be attached to this same bottle , an uninterrupted supply of air would be available at the diver's fingertips from the time a casualty occurs until he completes his in water decompression.

This proposal has the potential of providing better continuous gas flow to the diver. It also allows the design of the umbilical/reel system to be smaller and lighter since the umbilical hose does not have to be as large as a system that must accommodate peak flow rates. The diver's flow demand will be met by the pressure maintained in the bottle. The smaller hose would maintain this pressure with a flow throughout the entire respiratory cycle.